Investigating the effects of laser power density, pulse duration and viewing angle on a 6.7nm BEUV source

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Utsunomiya University Experiments,
September - November 2011

Contents

- Motivation – Interest in Gd, 6.7 nm and shorter wavelength sources
- Experiment 1 – Investigation of the effect of pulse duration and laser intensity on Gd plasma as a viable future lithography source
- Experiment 2 – Investigation of the effect of viewing angle on the spectral behaviour of a Gd plasma source near 6.7nm
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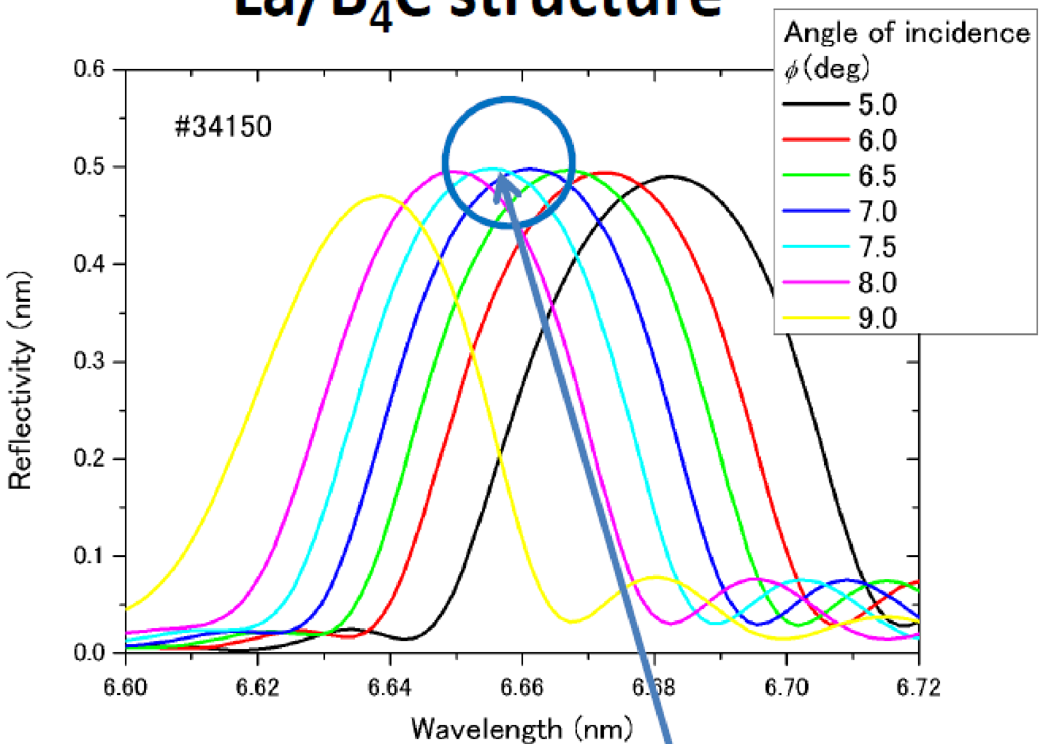
La/B_4C structure



Measurements at New Subaru,
May, 2011

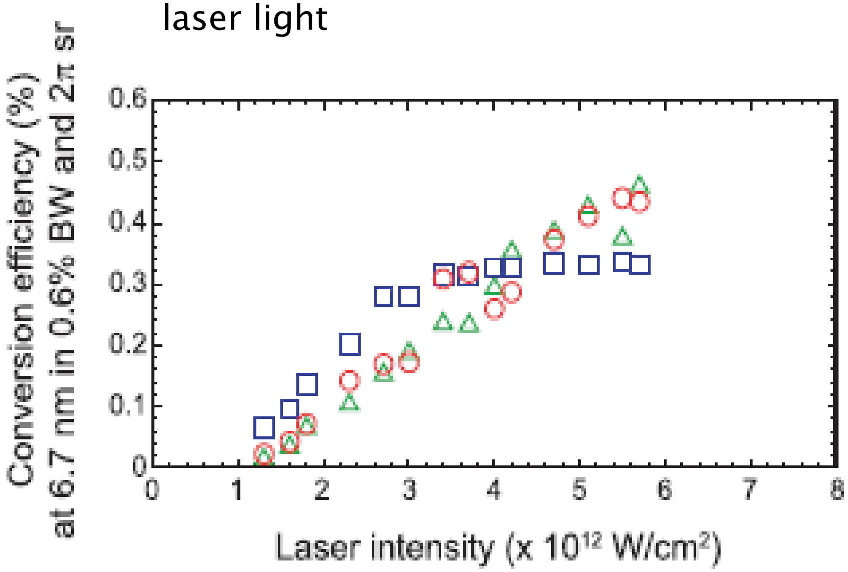
R(max)=49.83% at ~6.656nm

Y. Platinov et al., "Status of multilayer coatings for EUV Lithography" 2011 Int. Workshop on EUV Lithography, Hawaii

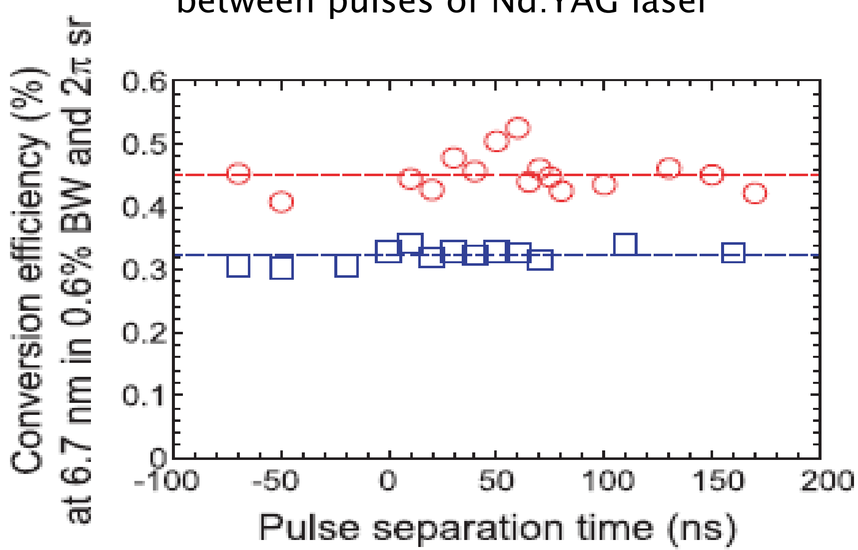
Recent results

- Maximum CE of 0.44% for mass limited target and 0.52% for double pulse scheme. Defined by 0.6% BW of MLM

Mass limited Gd targets; 10% – green triangles, 30% – red circles and 100% – blue squares. Irradiated with 1.06 μm laser light



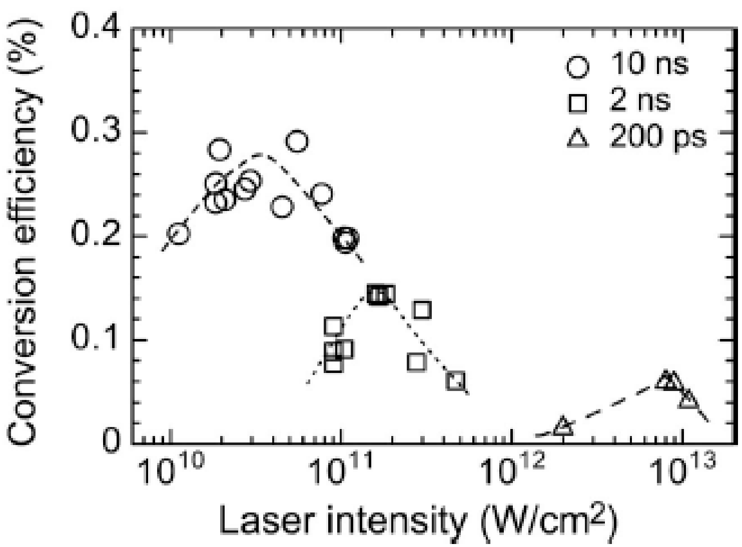
Dashed lines correspond to single shots of 30% (red) and 100% (blue) Gd. Double pulse using delay between pulses of Nd:YAG laser



Higashiguchi et al. (2011) Appl. Phys. Lett. **99**, 191502

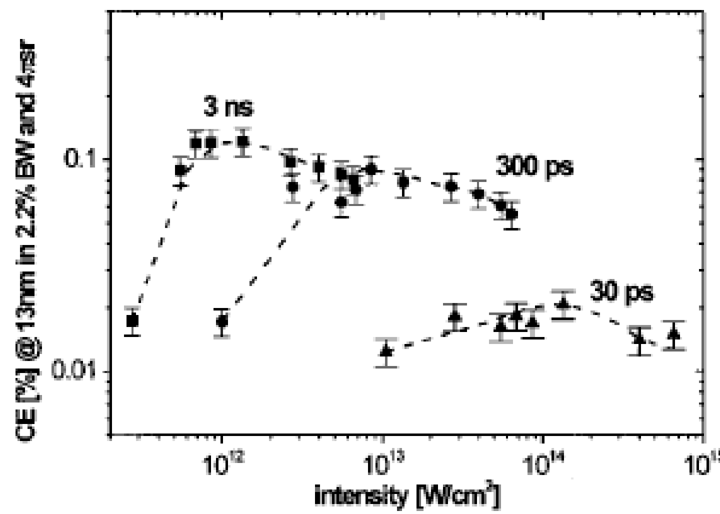
Effects of laser intensity and pulse duration on EUV emission

Pumping of pre formed plasma, with CO_2 laser on liquid Xenon microjet targets (4*d*–4*f* resonant transition lines of 7^+ – 11^+ ions)



Ueno et al. (2007) Appl. Phys. Lett. **90**, 191503

Nd:YLF (1047 nm) irradiation of a thin liquid water jet target (12.99 and 12.85 nm oxygen lines)



Vogt et al. (2001) Appl. Phys. Lett. **79**, 2336

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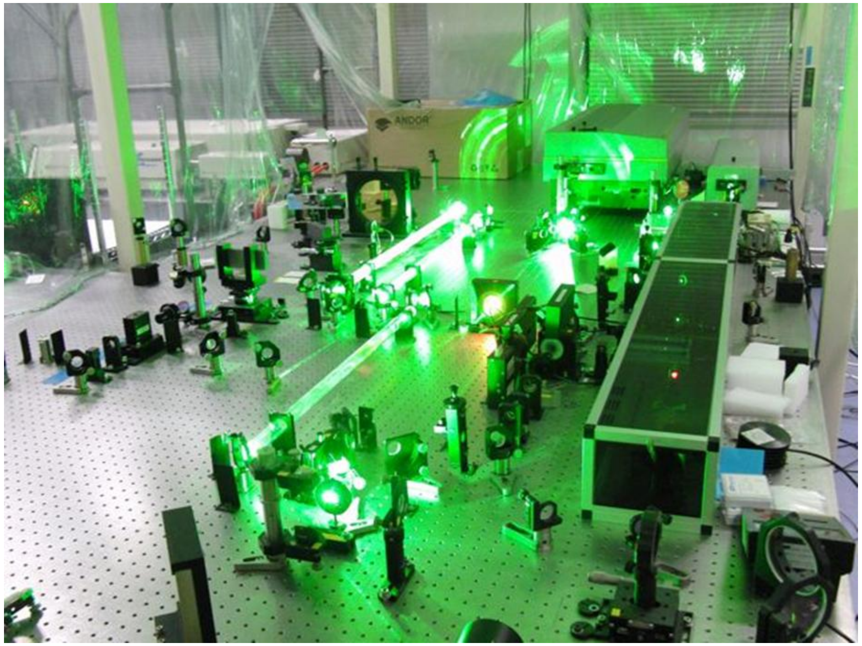
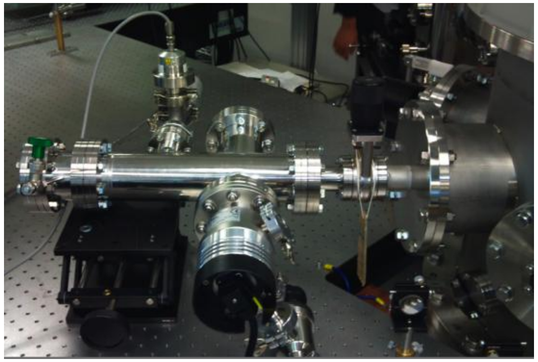
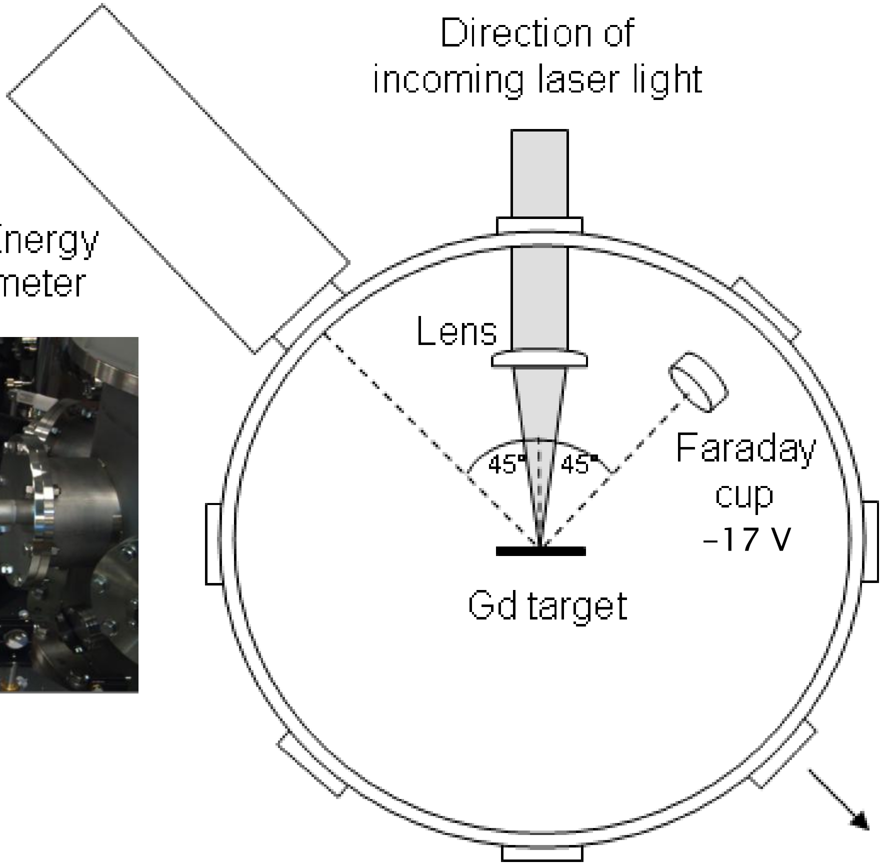
Laser Systems

	T	λ	E_{max}
Nd:YAG	10 ns	1064 nm	420 mJ
Nd:YAG	150 ps	1064 nm	210 mJ
Ti:Sapphire	140 fs	800 nm	30 mJ

Laser intensity range:
10^{11} – 10^{15} W/cm^2

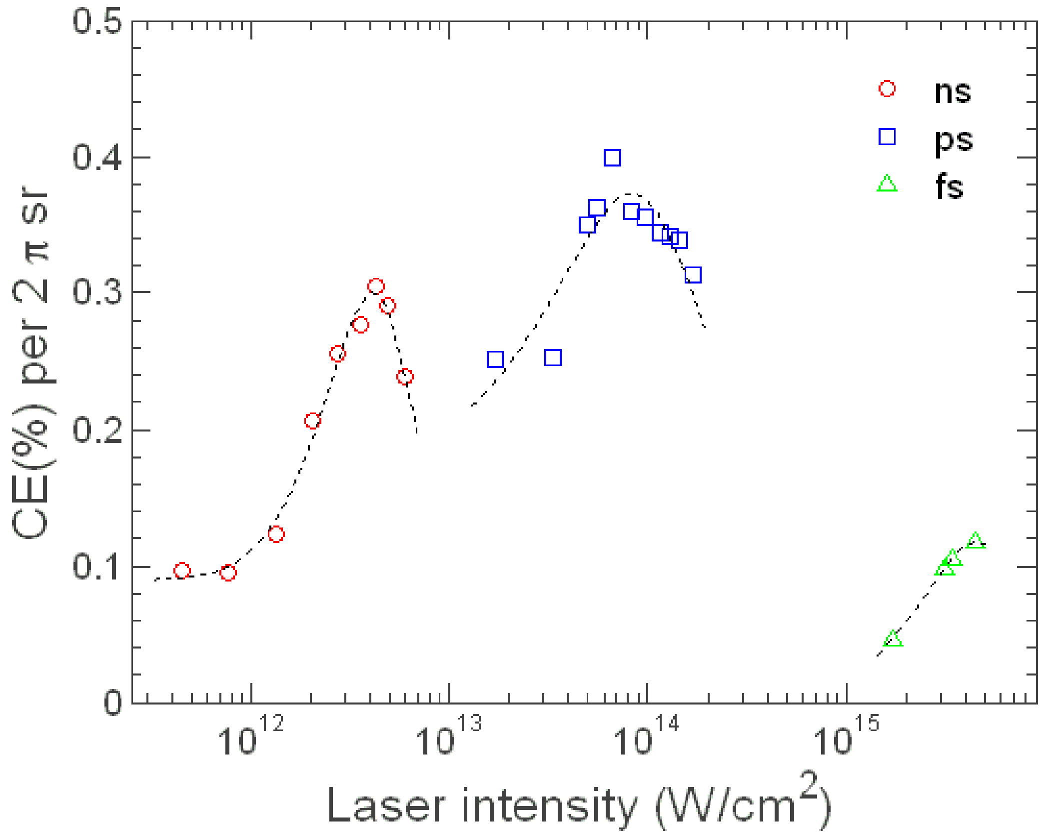






Schematic of experimental set-up

EUV emission



CE Defined within a 0.6% bandwidth of La/B_4C mirrors in 2π sr,centered on 6.76 nm. Max 0.4% @ 7 × 10^{13} W cm^{-2}

T. Cummins et al. Appl. Phys. Lett. 038207

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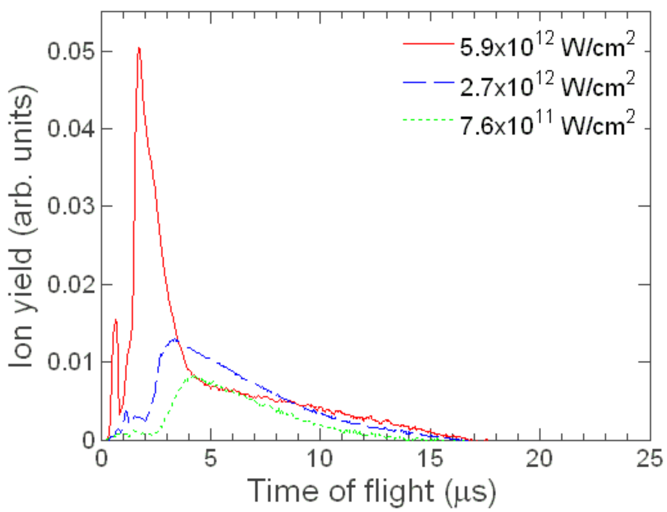
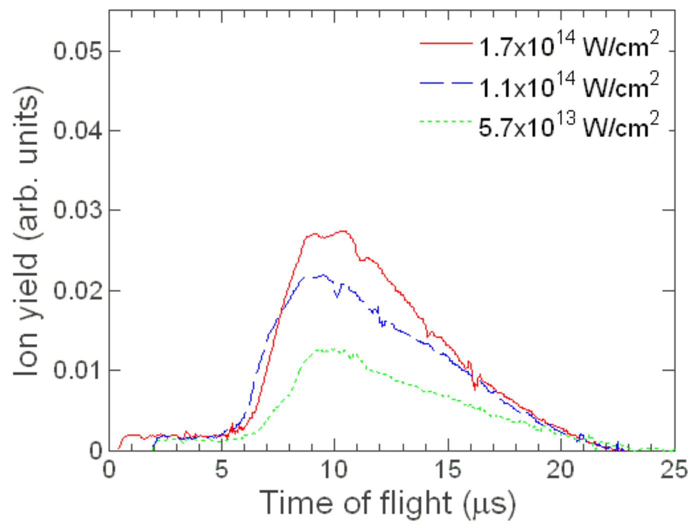
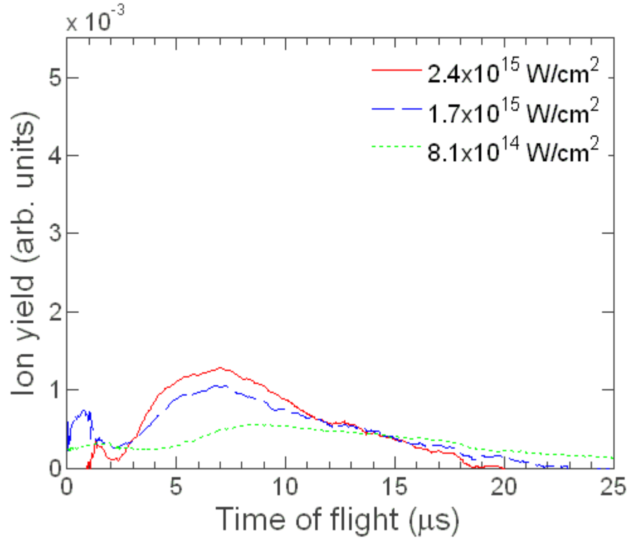
Faraday cup signals





ps laser

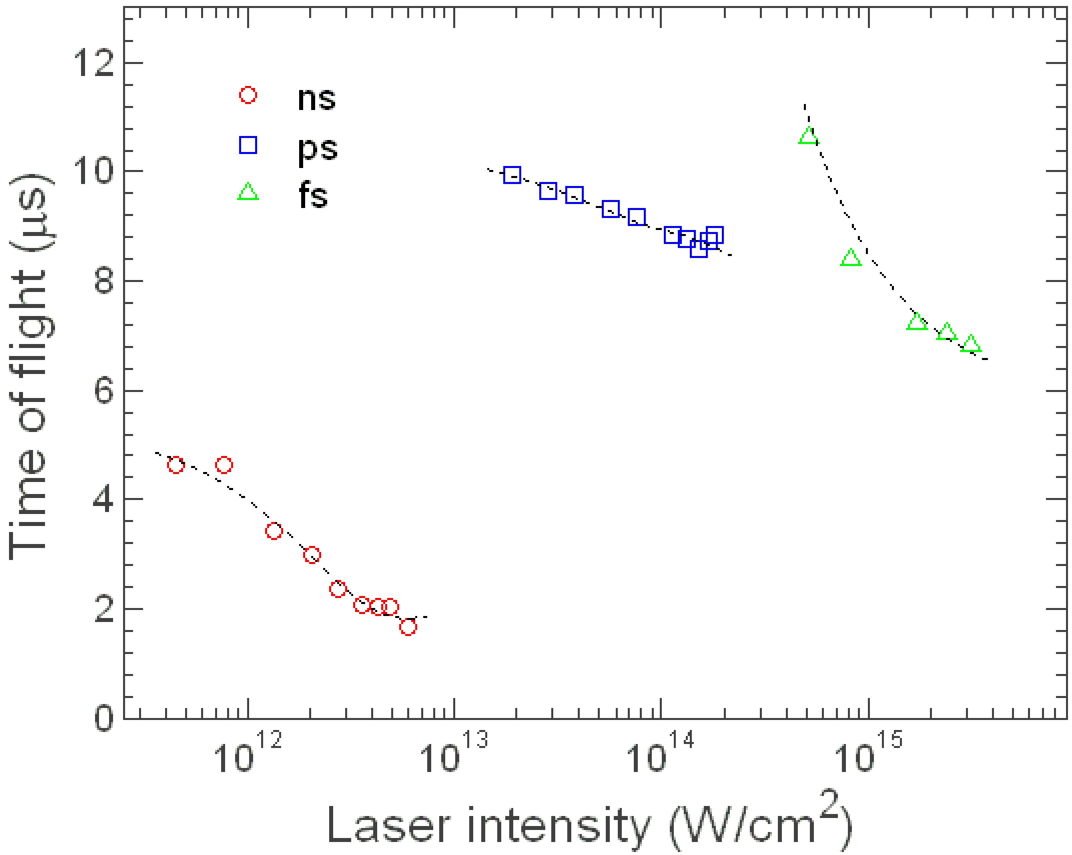
ns laser



fs laser

(note scale)

TOF signals



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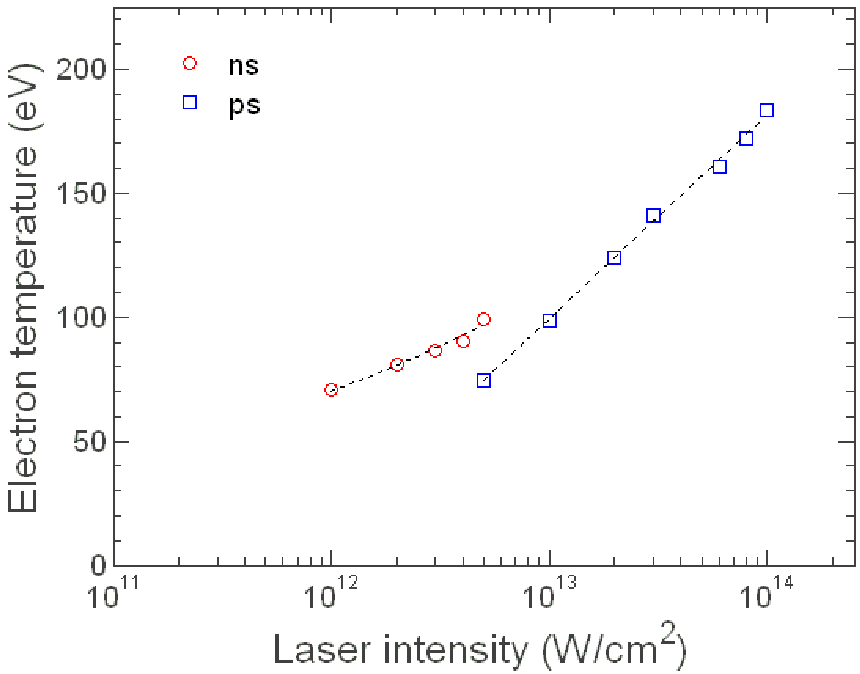
Time of flight

- Longer flight times recorded for ions from the ps and fs LPPs than from ns LPPs
- 2 µs for optimum intensity of ns laser and 9 µs for optimum intensity of ps laser
- Due to smaller plasma source created, meaning a smaller electrostatic potential for accelerating ions
- **Therefore ps Nd:YAG demonstrated both an increase in TOF and increased CE**

Electron Temperature

- Electron temperature dependence on laser intensity demonstrated for high-Z material, using a 1-D hydrodynamic code and λ=1.06 μm
- ϕ of 7×10^{13} W/cm^2 generates T_e close to 130 eV



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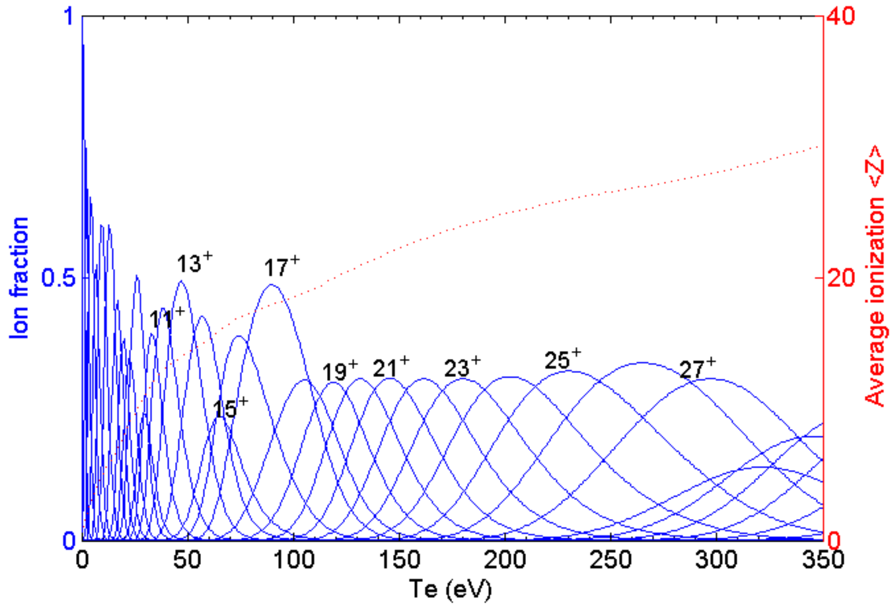
Calculation by Hao Tan

Comparison with CR model

- By use of a steady-state collisional radiative (CR) model, Gd ion populations calculated at 1×10^{21} cm^{-3}
- Producing optimum ion population requires tuning of the T_e between 80 to 130 eV



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Calculation by Bowen Li

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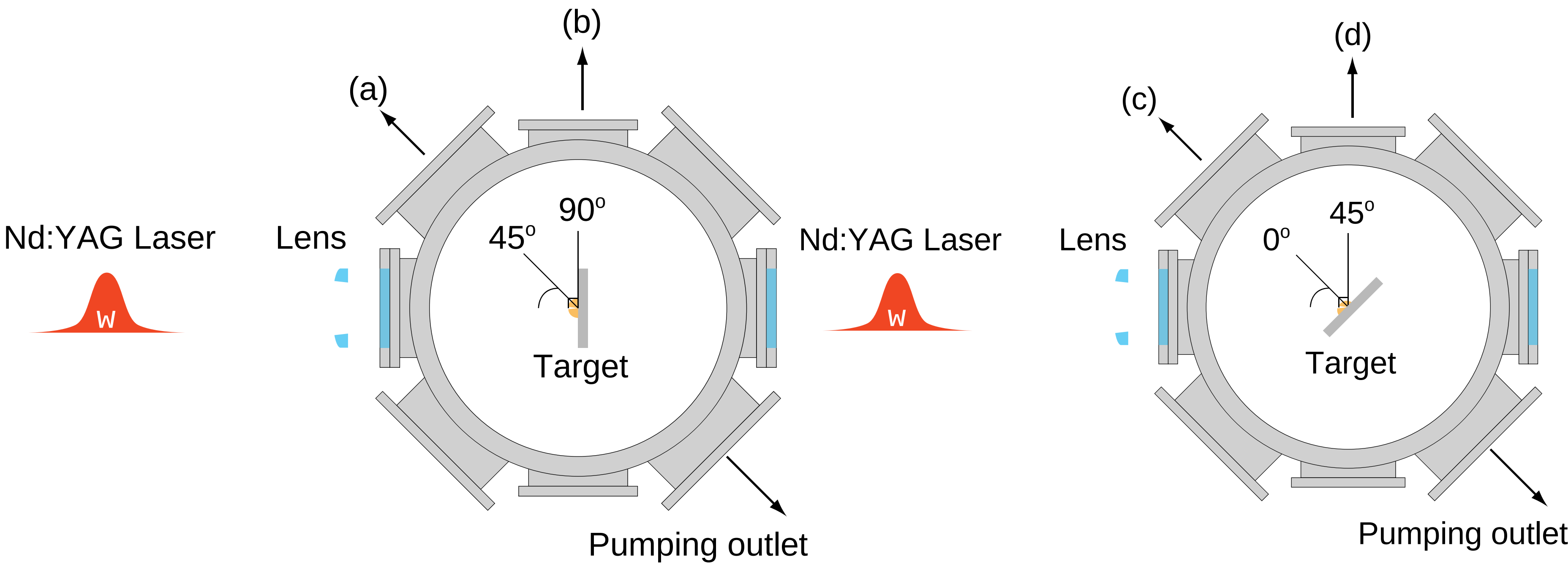
Experimental setup

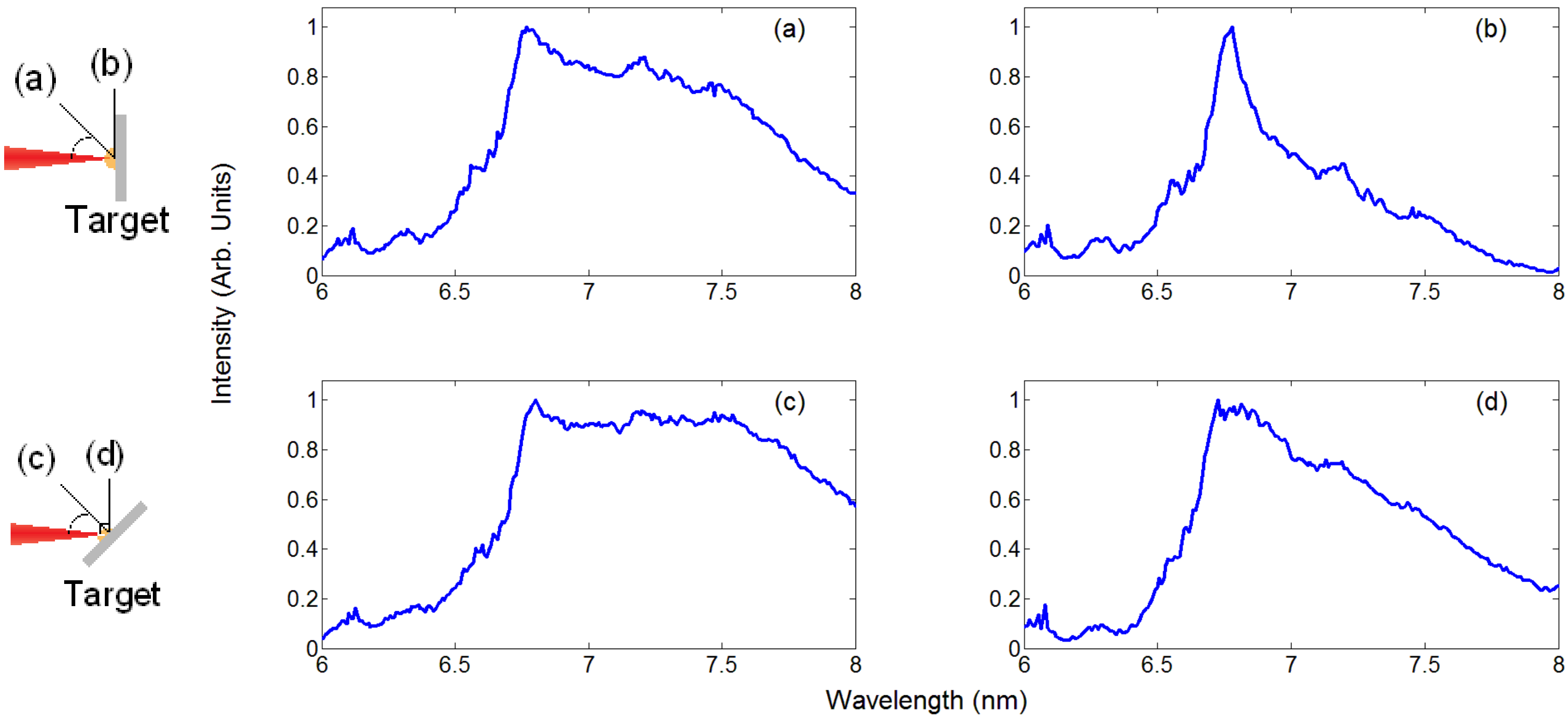


f = 10 cm , spot size = 30 – 40um

λ= 1064 nm

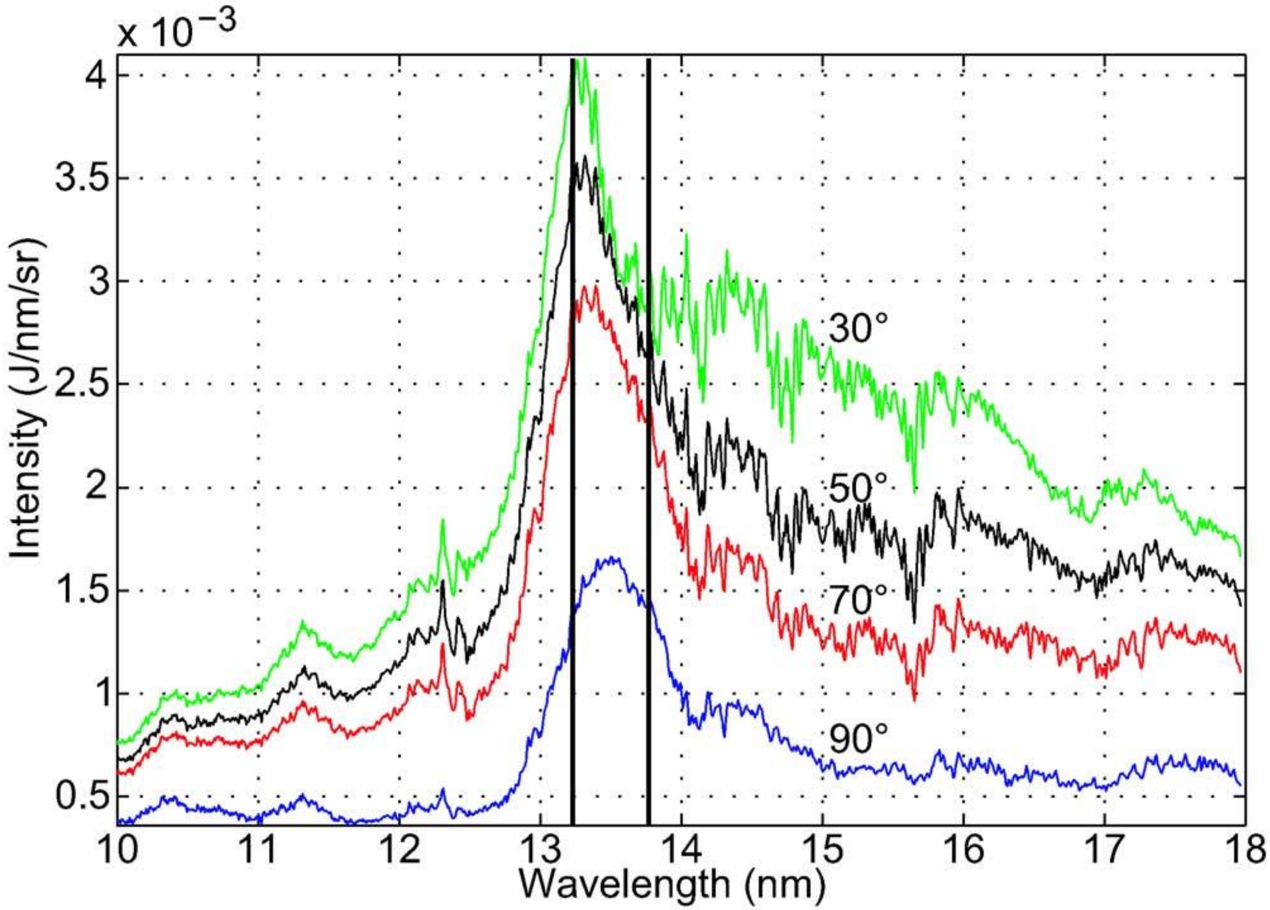
t = 10 ns or 150 ps

10 ns laser angular emission dependence



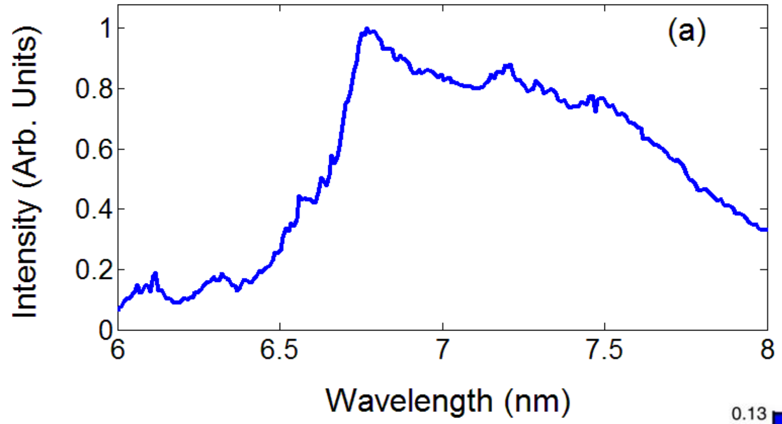
C O'Gorman et. al – Appl. Phys. Lett – **100** –141108 (2012)

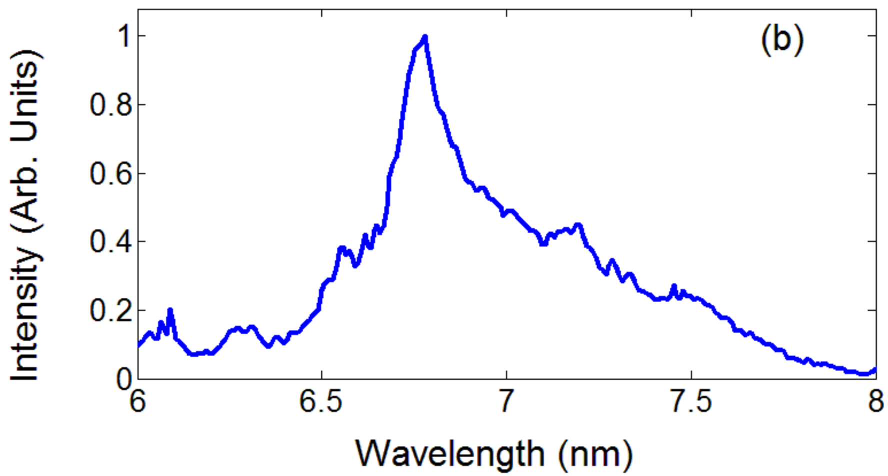
Sn previous results

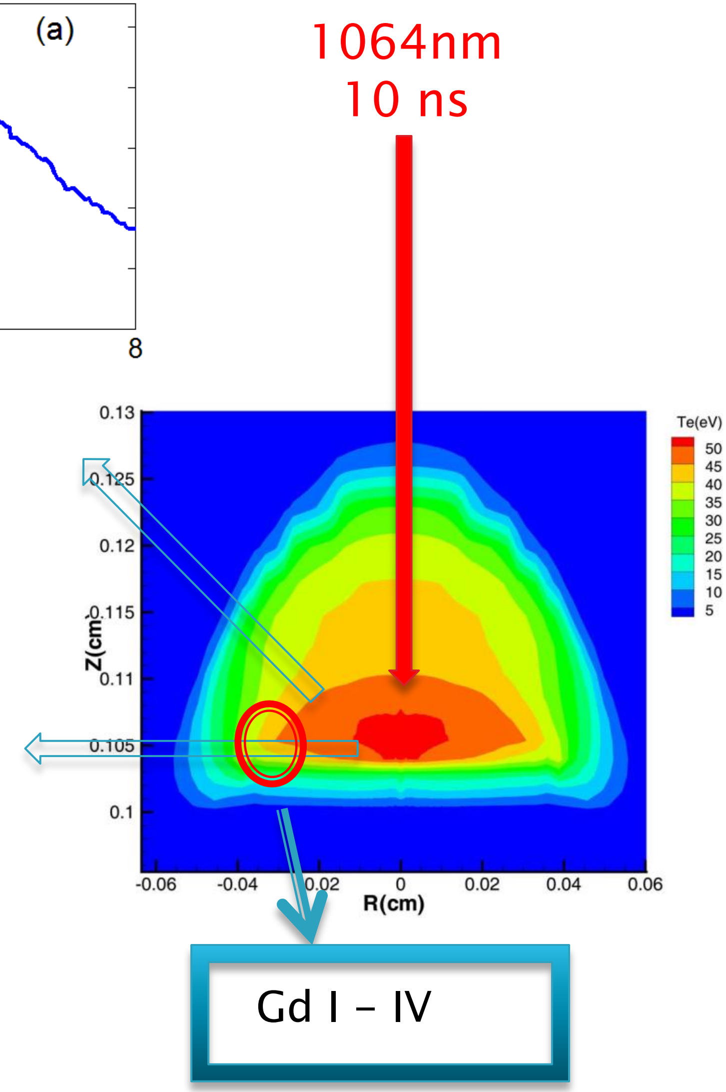


Morris et. al (Appl. Phys. Lett – 92 -231503)

Gd angular emission

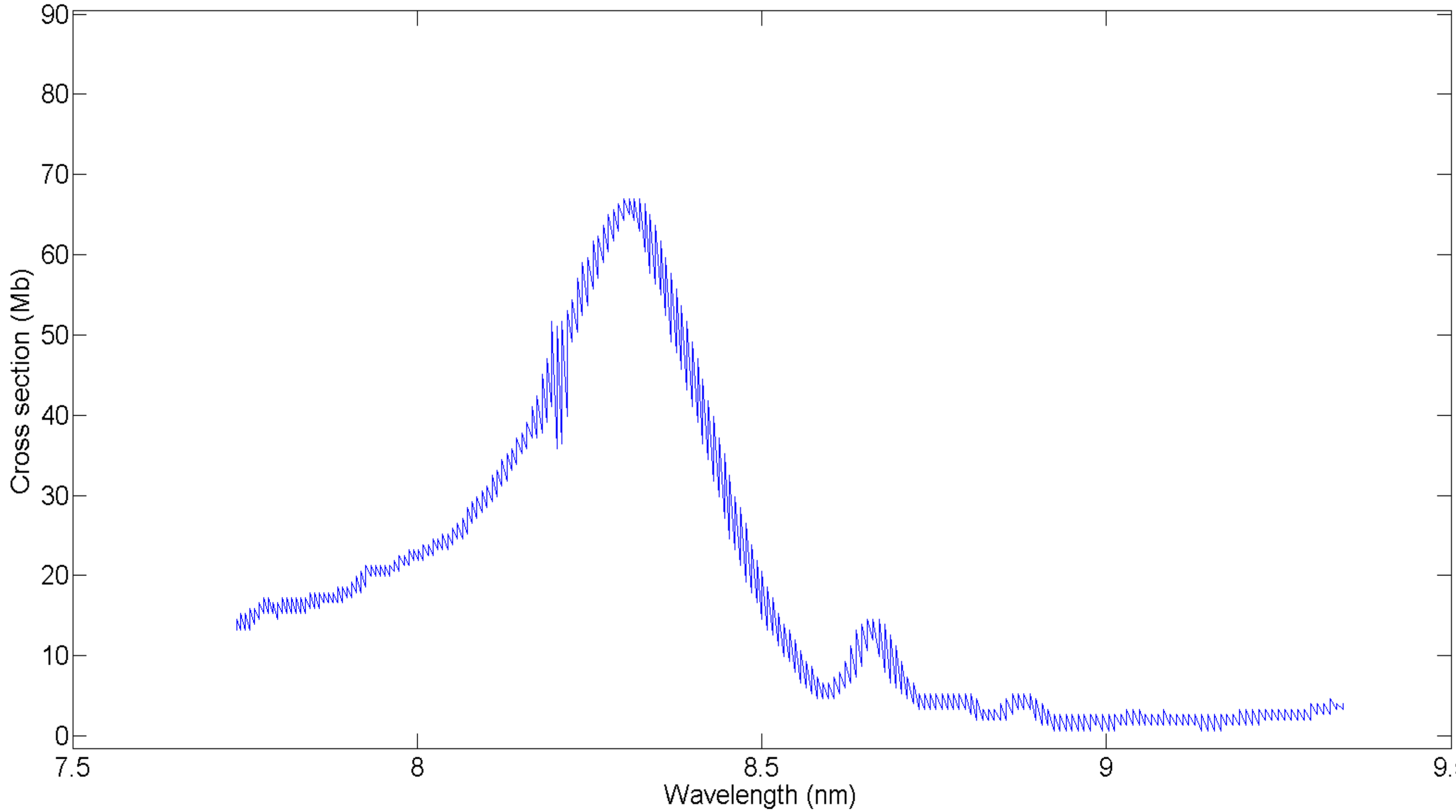






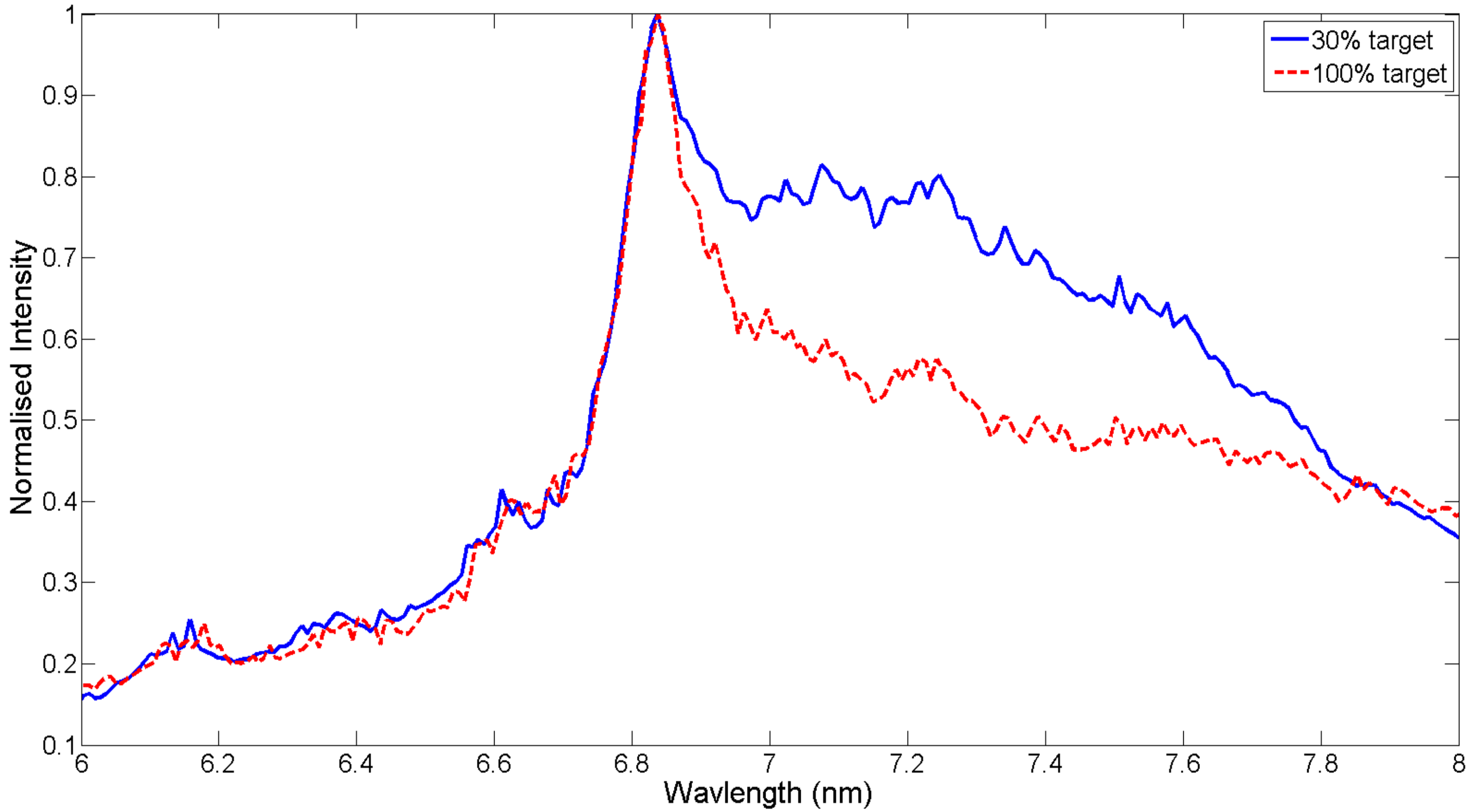
[1] –J. White et. Al (Appl. Phys. Lett. **92** 151501 (2008))

Gd absorption Spectroscopy



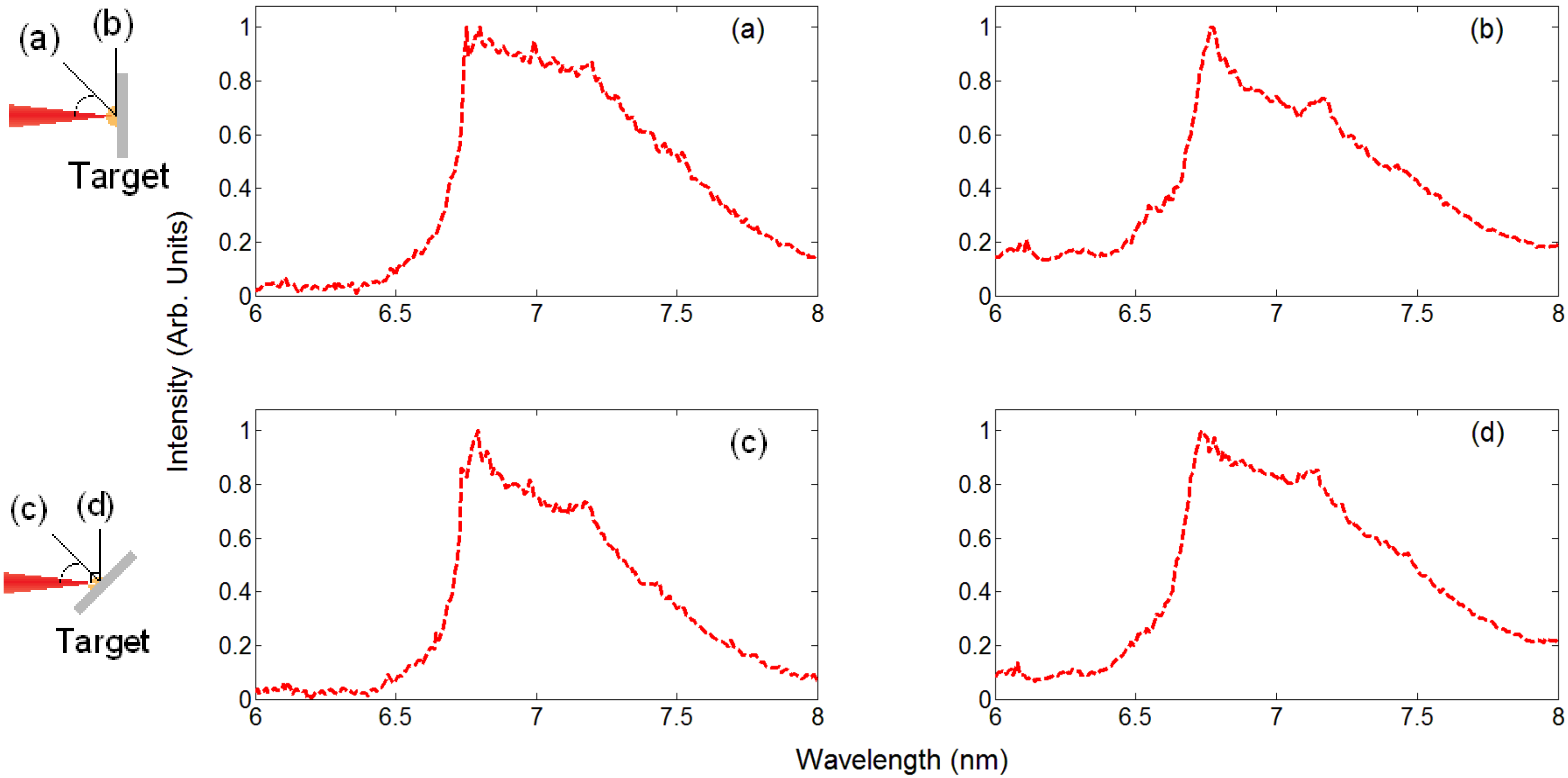
M. Richter, et.al Phys. Rev. A **40** 7007 – 7019

30% “foam” Gd



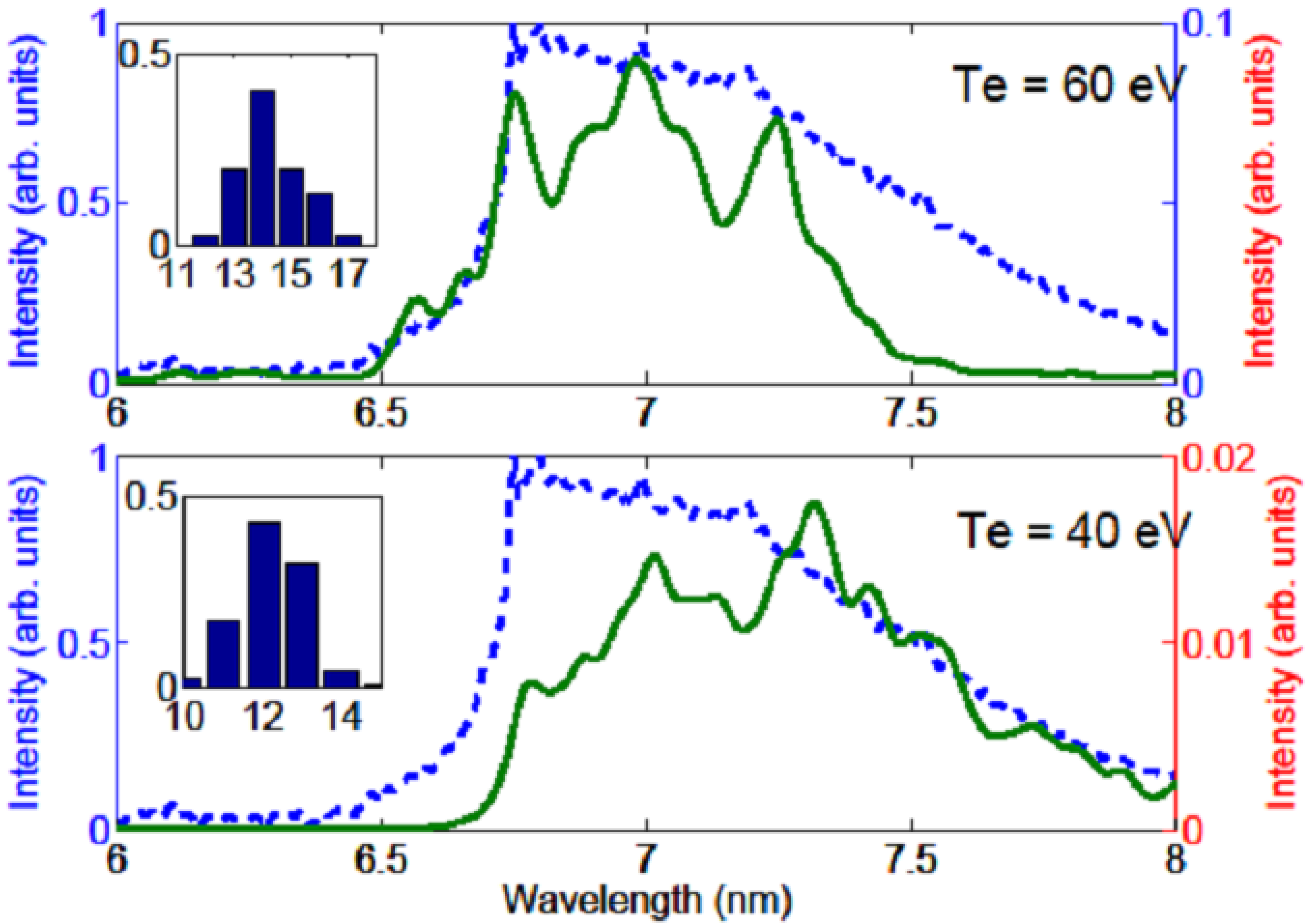
C O’Gorman et. al – Appl. Phys. Lett – **100** –141108 (2012)

150ps laser



C O'Gorman et. al – Appl. Phys. Lett – **100** –141108 (2012)

Theoretical/ Experimental comparison



C O'Gorman et. al – Appl. Phys. Lett – **100** –141108 (2012)

Conclusions

- Maximum CE of 0.4% achieved with ps at 7×10^{13} W/cm^2
- However, emission not optimized due to some EUV suppression by self absorption effects
- Ion TOF from ps laser produced plasma is greater than double that compared to that of ns. Hence lower ion kinetic energy
- This will assist with debris mitigation and reduce the damage to optical components by fast ion bombardment

Conclusions

- There may be an optimum angle for collection
- Typical experimental setup – fixed angle of measurement
- Isotropic emission assumed – extrapolated in to 2pi
- Target geometries and angle of measurement must be reported along with CE

Gd as a future source

- Results point towards use of ps lasers, perhaps carbon dioxide (CO_2), for optimum EUV emission from Gd plasma
- Emission will increase due to the reduction in opacity and produce ions with prolonged flight times
- Mass limited targets or novel plasma targets required
- Gd, in some form, can play a significant role in future application as a BEUV source
  - Sn (droplet target)
    - Melting point: 505.05 K
    - Boiling point: 2543.15 K
  - Gd (planar target?)
    - Melting point: 1584.15 K
    - Boiling point: 3506.15 K

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Speclab

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- Collaborators: DCU: Prof. John Costello, Dr. Paddy Hayden, Colm Fallon, TCD: Prof. James Lunney and Issac Tobin
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Thank You